SXT Mirror Technology Development

Will Zhang

X-ray Astrophysics Laboratory

NASA Goddard Space Flight Center

Mirror Technology Development Team

K.W. Chan[1], D.A. Content, T.J. Hadjimichael[2], Charles He[2], M. Hong[3], L. Kolos, J.P. Lehan[1], J.M. Mazzarella[3], R. McClelland[3], D.T. Nguyen, L. Olsen[3], S.M. Owens, R. Petre, D. Robinson, R. Russell[3], T.T. Saha, M. Sharpe[3], J. Sturm, T. Wallace, W.W. Zhang

NASA Goddard Space Flight Center

[1] also University of Maryland, Baltimore County

[2] Ball Aerospace and Technologies Corp.

[3] Stinger Ghaffarian Technologies, Inc.

M.V. Gubarev, W.D. Jones, S.L. O'Dell

NASA Marshall Space Flight Center

D. Caldwell, W. Davis, M. Freeman, W. Podgorski, R. Rasche, P.B. Reid, S. Romaine

Smithsonian Astrophysical Observatory

SXT Mirror Technology Development Charter

- Identify problems unique to Con-X SXT mirrors that have not been encountered or solved for previous missions
- Devise solutions to these problems; Demonstrate their validity through analysis and experimentation
- Establish design principles and build prototypes to prove that they meet requirements
- Subject the prototypes to x-ray and appropriate environment tests to demonstrate TRL-6

The Fourfold Challenge

- Meeting performance requirements: angular resolution and effective area
- Meeting mass requirements
- Minimizing production cost
- Minimizing production schedule

The Four "Simple" Tasks

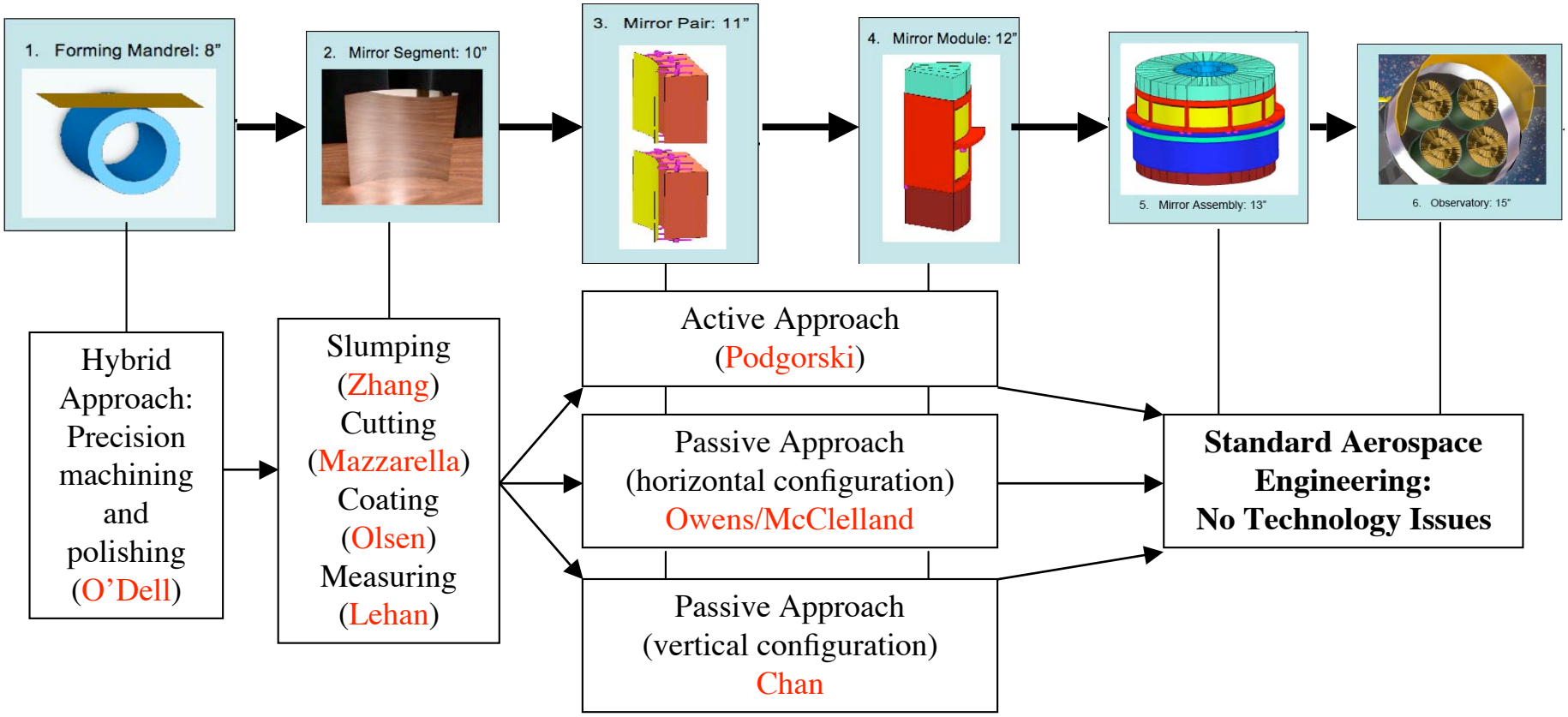
- Make forming mandrels
- Make mirror segments
- Measure and qualify mirror segments
- Align mirror segments and affix them to a permanent housing

The devil is in the details! The devil is in the details! The devil is in the details! The devil is in the details! The devil is in the details! The devil is in the details!

Major Accomplishments since Last FST

- Bonded, aligned, and X-ray tested a pair of mirrors, achieving 15" HPD at 8 keV (Rohrbach, Olsen et al.)
- Reduced mirror sag error from ~13" to ~6"; Reduced mid-frequency error, obviating epoxy replication (Zhang et al.)
- Implemented whole-surface mirror metrology (Lehan et al.)
- Began the investigation of multiple alignment and mount methods:
  - Horizontal passive mount (Rohrback et al.)
  - Vertical active mount (Podgorski et al.)
  - Vertical passive mount (Chan et al.)
- Completed glass strength test (He et al.)
- Began parametric study to minimize stress load on mirror segments (Freeman et al.)
- Began forming mandrel technology development (O'Dell et al.)

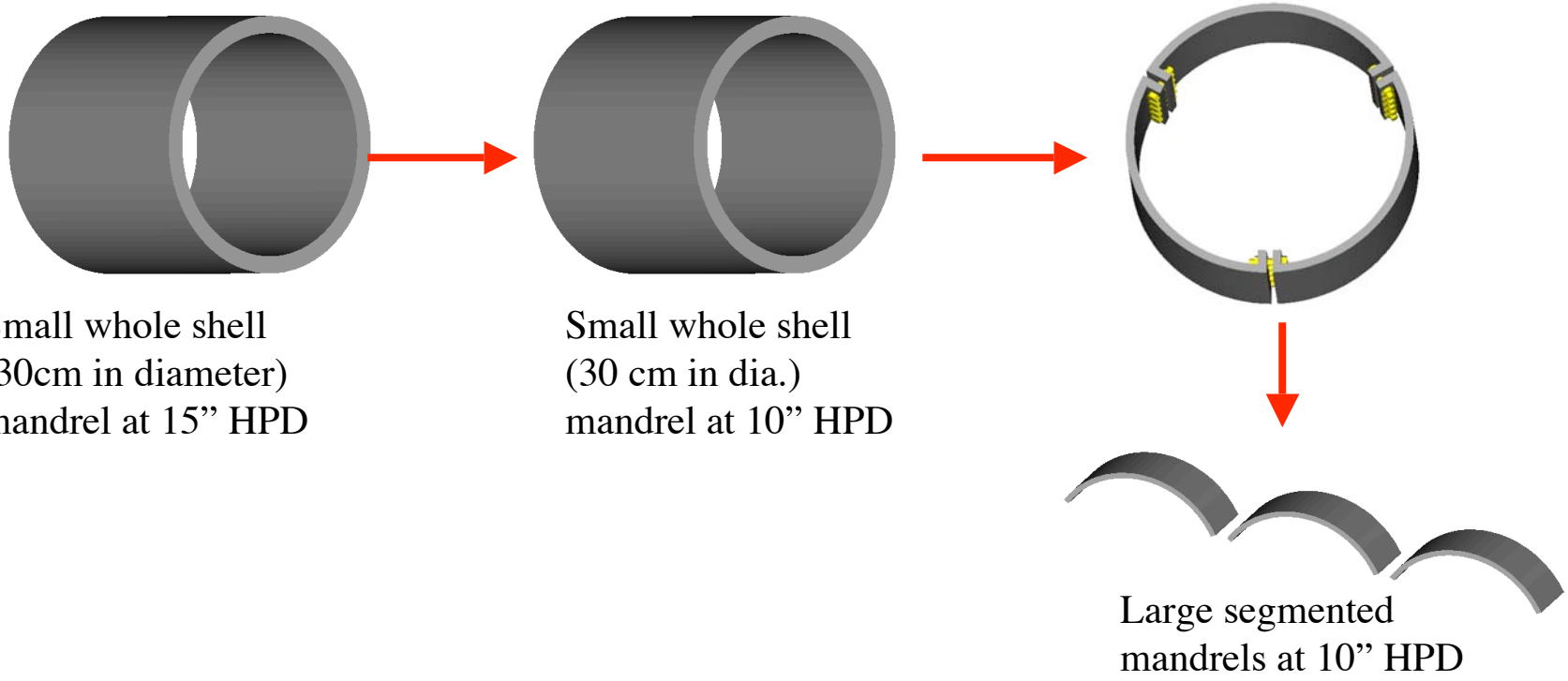
SXT Mirror Technology Roadmap



Development of forming mandrel fabrication technology (O'Dell et al.)

- Take advantage of the precision machining technology that has been developed in industry over the last two decades
- Take advantage of the axial symmetry of X-ray optics
- Apply knowledge and lessons learned in the last few years from our mandrel fabrication efforts both in-house and in industry: (1) material selection and (2) fabrication techniques, etc.
- Enable faster and cheaper production of better forming mandrels

Development of forming mandrel fabrication technology (O'Dell et al.)



Small whole shell
(30cm in diameter)
mandrel at 15" HPD

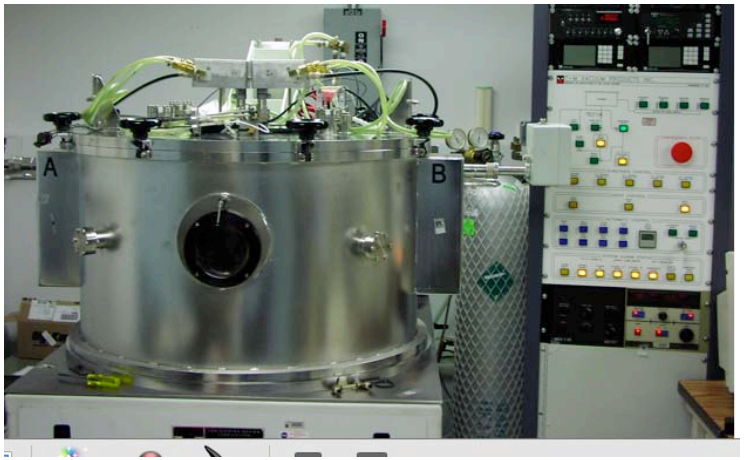
Small whole shell
(30 cm in dia.)
mandrel at 10" HPD

Large segmented
mandrels at 10" HPD

Fabrication of mirror segments (Zhang et al.)

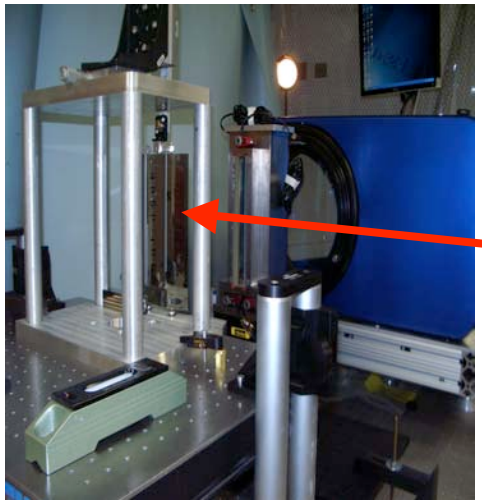
Slumping

Post-slumping trimming

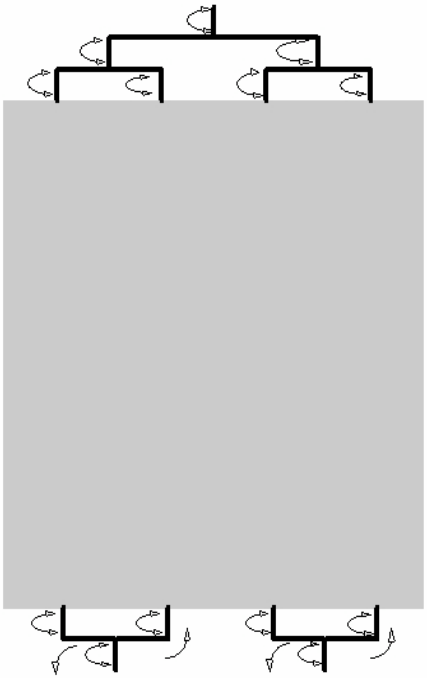


Ir-coating

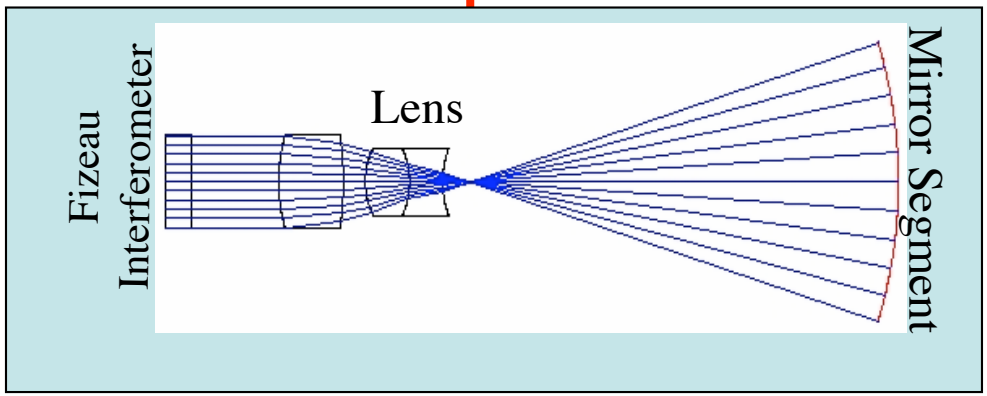
Mirror segment metrology (Lehan et al.)



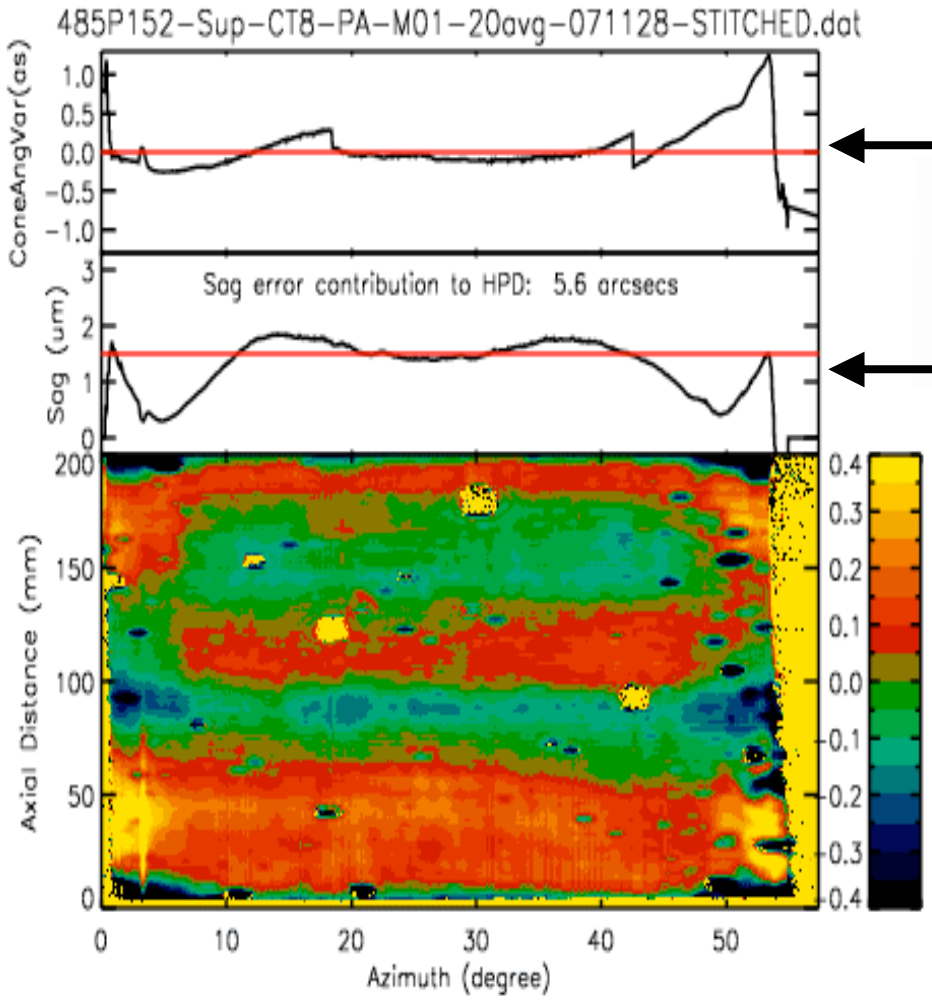
Implementation



Mirror support concept



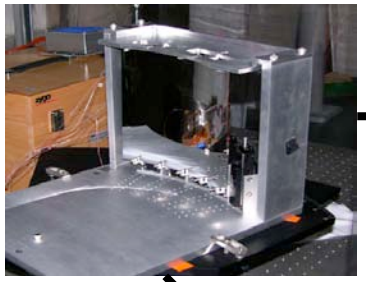
Status of mirror fabrication

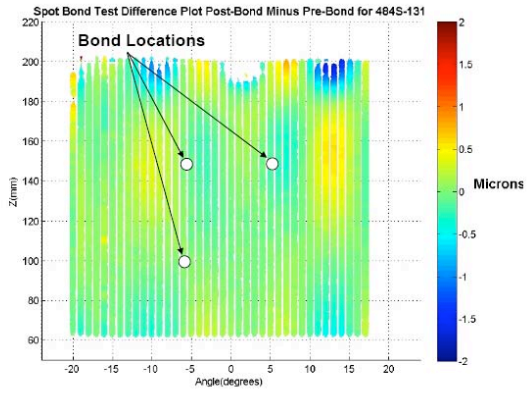


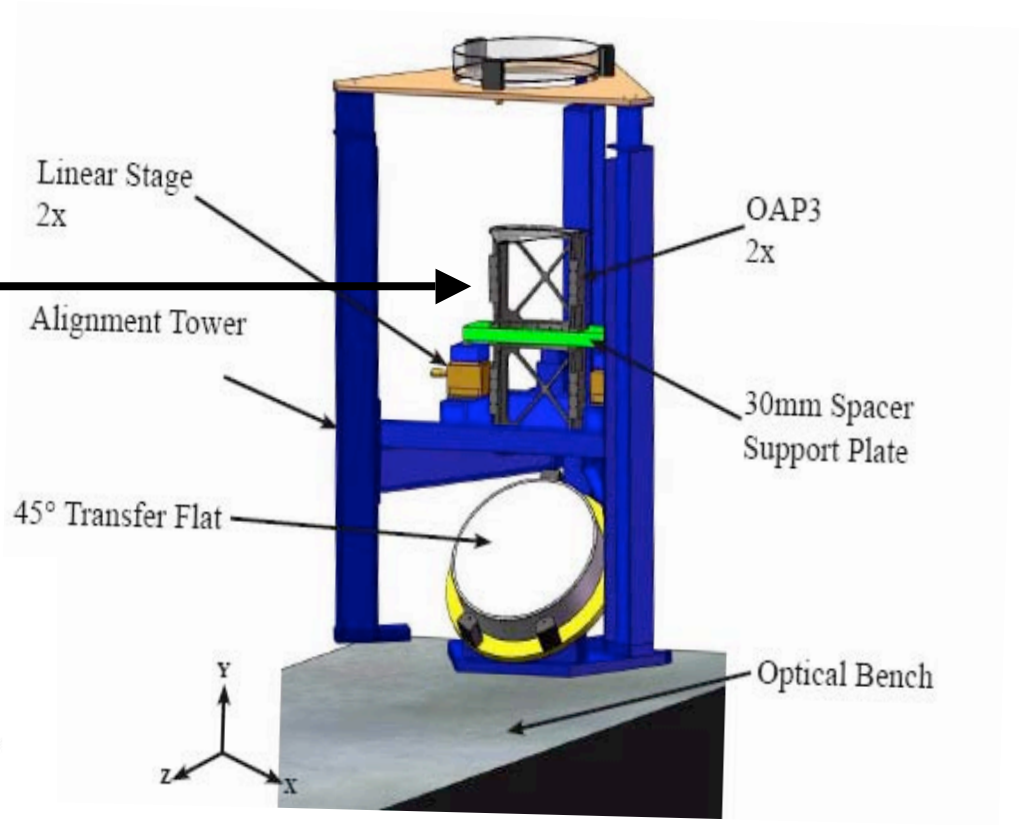
$$\rho(\phi,z) = \rho_0(\phi) + z \cdot \tan\theta(\phi) + \left(\frac{2z}{L}\right)^2 \cdot s(\phi) + R(\phi,z)$$

Mirror alignment: Active
Vertical Configuration (Podgorski et al.)

Single mirror in temporary mount

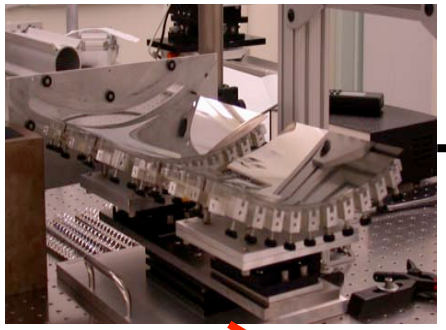




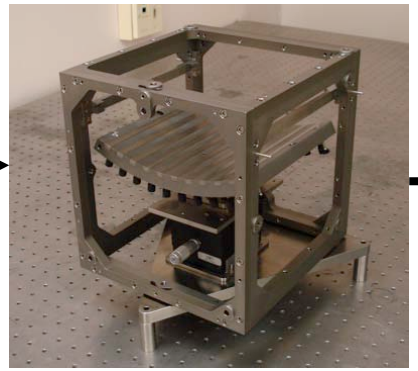


Mirror alignment: Passive Horizontal Configuration (Rohrbach et al.)

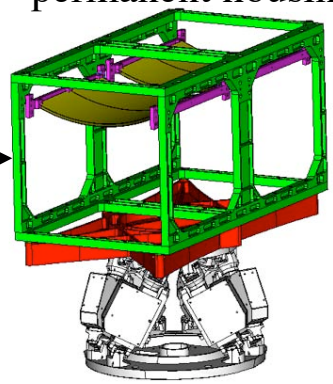
Mirror pair in temporary mount



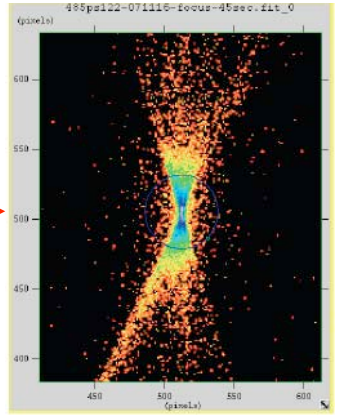
Single mirror in permanent mount



Mirror pair in permanent housing

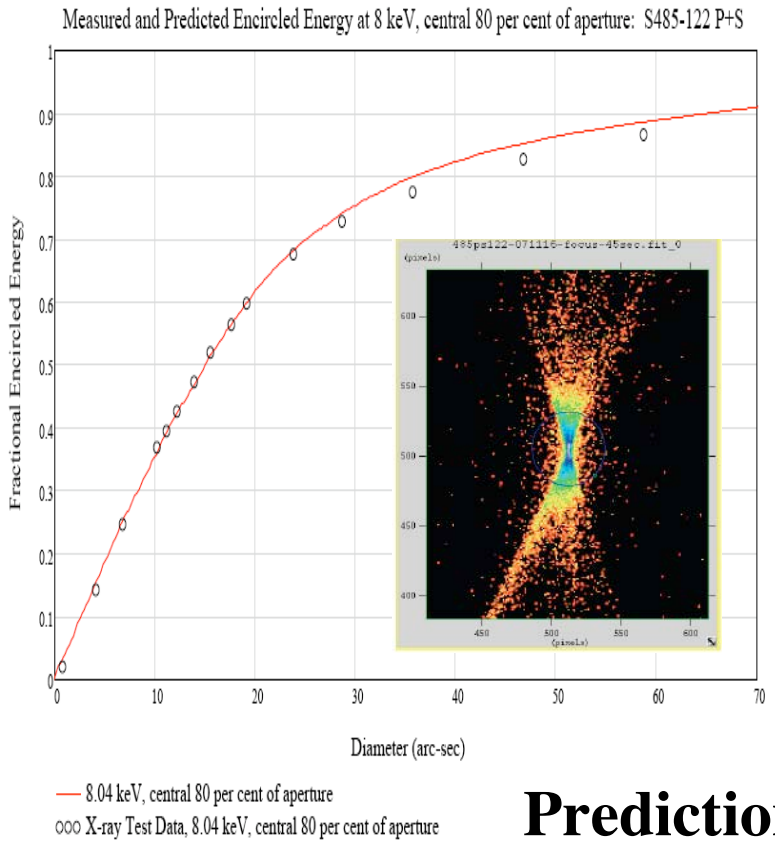


Mirror pair in x-ray test chamber



X-ray Image:
14.7 arcsecs HPD
@ 8 keV
As predicted with optical metrology data

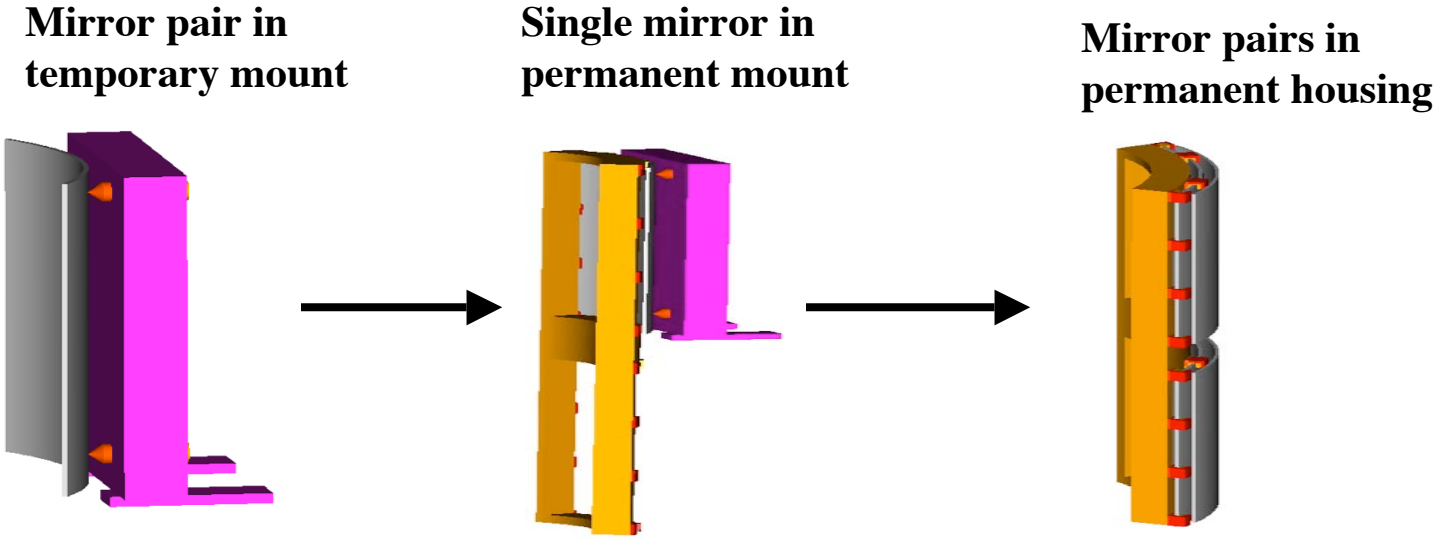
Comparison of prediction and measurement (Reid et al.)



- Confirms mirror metrology and performance prediction
- Shows that the mirror surface quality is good enough without epoxy replication

Prediction for another pair: 13" HPD at 8 keV, to be x-ray tested in coming weeks

Mirror alignment: Passive Vertical Configuration (Chan et al.)



Status and Outlook

		Now			Future		
Quantity		Potential Source of Error	Existing Evidence?	Contribution to HPD (")	Method to Reduce or Eliminate Error	Contribution to HPD after Mitigation (")	Comment
Average radius		CTE mismatch between mandrel and glass sheet	Maybe	0	Account for CTE mismatch in mandrel prescription	0	Easy
		Measurement distortion	Yes	0	Perfect mirror support mechanism	0	Moderately hard
		Unannealed thermal stress	Maybe	0	Prolong cooling cycle and use coating stress to counter thermal stress	0	Hard
Focal length (average cone angle)		Forming mandrel	Yes	0	Apply more stringent quality requirements on mandrel	0	Easy
		Forming process	No	0	Devise solution when necessary	0	Easy
Focus quality (cone angle variation)		Unannealed thermal stress	Maybe	1	Prolong cooling cycle and use coating stress to counter thermal stress	1	Maybe easy
		Measurement distortion	Yes	4	Perfect mirror support mechanism	0	Moderately hard
Sag		Forming mandrel	Yes	0	Apply more stringent quality requirements on mandrel	0	Easy
		Coating stress	Maybe	0	Reduce/eliminate it or balance it	0	Maybe easy
		Measurement distortion	Yes	6	Perfect mirror support mechanism	0	Moderately hard
		Unannealed thermal stress	Maybe		Prolong cooling cycle and use coating stress to counter thermal stress	1	Maybe hard
Axial figure	Low frequency figure	Forming mandrel	Yes	5	Apply more stringent quality requirements on mandrel	2	Easy
		BN-coating changing mandrel sag	No	0	Devise solution when necessary	0	Easy
		Thermal stress due to inadequate annealing	Yes	0	Prolong cooling cycle	0	Maybe easy
	Mid frequency figure	Forming mandrel	No	0	Apply more stringent quality requirements on mandrel	0	Maybe easy or maybe hard
		BN-coating changing mandrel figure	Yes	8	Improve application and buffing techniques; RF-sputter; Reactive sputter	3	Hard
		Maximum forming temperature	Yes	0	Optimize as necessary to achieve optimal balance between mid and low frequency figure	0	Easy
	High frequency figure	Forming mandrel	No	0	Apply more stringent quality requirements on mandrel if necessary	0	Easy
		Glass sheet quality	Yes	2	Super-polish glass sheets if necessary	2	Moderately hard
Mirror Pair Performance HPD (")				12		4	

Challenges for 2008

- Mirror fabrication
  - Reduction of mid-frequency error caused by BN coating on the mandrel: better buffing and better BN deposition
  - Reduction of sag error: (1) Reduction of thermal stress with longer anneal time; (2) Balance of thermal stress with coating stress to achieve better figure
  - Better forming mandrels
- Mirror attachment
  - Bonding with acceptable distortion
  - Bonding with acceptable movement
  - Alignment and integration of multiple mirror segments

Acknowledgements

The work is supported in part by

Constellation-X Project Office

Goddard Space Flight Center Internal Research and Development Fund

A NASA *Astronomy and Physics Research and Analysis* Grant

SAO Internal Research Funds